

surface region between them, said common surface region comprising a valley adjacent the hole-exit, and a plateau adjacent the valley. The method comprises forming each inlet bore and chevron outlet by directing a contacting device or a contacting medium to a pre-selected region of the substrate, in a computer-controlled single- or repeated plunging motion, sweeping motion, or combined plunging-and-sweeping motion.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] FIG. 1 is a perspective view of an outer surface of a substrate, illustrating the general exit region of three passage holes which extend through the substrate.

[0017] FIG. 2 is a transverse sectional view, taken along line 2-2 of FIG. 1, of one of the passage holes illustrated in FIG. 1.

[0018] FIG. 3 is a plan view of the passage hole illustrated in FIG. 2, taken along line 3-3.

[0019] FIG. 4 is a transverse sectional view of a passage hole according to another embodiment of this invention.

[0020] FIG. 5 is a top view of the chevron outlet region of a passage hole according to an embodiment of the invention.

[0021] FIG. 6 is a top view of a portion of the chevron outlet region of a passage hole according to embodiments of the invention.

[0022] FIG. 7 is a transverse sectional view of a passage hole according to another embodiment of this invention.

[0023] FIG. 8 is a transverse sectional view of a passage hole and exit site region, for a substrate covered by a coating, according to embodiments of the invention.

[0024] FIG. 9 is a schematic perspective of a water jet cutting machine utilized in embodiments of the invention.

[0025] FIG. 10 is a schematic perspective view of a nozzle assembly for a water jet cutting machine related to the present invention.

[0026] FIG. 11 is an illustration of the motion of a plunging device forming passage holes in a substrate, according to some of the inventive embodiments.

[0027] FIG. 12 is an illustrated top view of the chevron region of a passage hole formed by a multi-plunge technique, according to the invention.

[0028] FIG. 13 is a schematic perspective of an electric discharge machining device useful for embodiments of the invention.

[0029] FIG. 14 is a schematic illustration of a laser-based system for producing passage holes according to embodiments of this invention.

DETAILED DESCRIPTION OF THE INVENTION

[0030] The numerical ranges disclosed herein are inclusive and combinable (e.g., ranges of “up to about 25 wt %”, or, more specifically, “about 5 wt % to about 20 wt %”, are inclusive of the endpoints and all intermediate values of the ranges). In terms of any compositional ranges, weight levels are provided on the basis of the weight of the entire composition, unless otherwise specified; and ratios are also provided on a weight basis. Moreover, the term “combination” is inclusive of blends, mixtures, alloys, reaction products, and the like.

[0031] Furthermore, the terms “first,” “second,” and the like, herein do not denote any order, quantity, or importance, but rather are used to distinguish one element from another. The terms “a” and “an” herein do not denote a limitation of

quantity, but rather denote the presence of at least one of the referenced items. The modifier “about” used in connection with a quantity is inclusive of the stated value, and has the meaning dictated by context, (e.g., includes the degree of error associated with measurement of the particular quantity).

[0032] Moreover, in this specification, the suffix “(s)” is usually intended to include both the singular and the plural of the term that it modifies, thereby including one or more of that term (e.g., “the passage hole” may include one or more passage holes, unless otherwise specified). Reference throughout the specification to “one embodiment”, “another embodiment”, “an embodiment”, and so forth, means that a particular element (e.g., feature, structure, and/or characteristic) described in connection with the embodiment is included in at least one embodiment described herein, and may or may not be present in other embodiments. In addition, it is to be understood that the described inventive features may be combined in any suitable manner in the various embodiments.

[0033] Any substrate which is exposed to high temperatures and requires cooling can be used for this invention. Examples include ceramics or metal-based materials. Non-limiting examples of the metals or metal alloys which might form the substrate include steel, aluminum, titanium; refractory metals such as molybdenum; and superalloys, such as those based on nickel, cobalt, or iron. The substrate can also be formed of a composite material, such as a niobium silicide intermetallic composite.

[0034] Very often, the substrate is at least one wall of a gas turbine engine component. This type of wall, and the turbine components themselves, are described in many references. Non-limiting examples include U.S. Pat. No. 6,234,755 (Bunker et al) and U.S. Pat. No. 7,328,580 (Lee et al; hereinafter “Lee”), both of which are incorporated herein by reference.

[0035] The Lee reference comprehensively describes an aviation gas turbine engine which is axisymmetrical about a longitudinal or axial centerline axis. The engine includes, in ordered flow communication, a fan, a multistage axial compressor, and an annular combustor, which is followed in turn by a high pressure turbine (HPT) and a low pressure turbine (LPT).

[0036] The HPT usually includes a turbine nozzle, having a row of hollow stator vanes supported in inner and outer nozzle bands. A first stage turbine follows the first stage turbine nozzle and includes a row of hollow rotor blades extending radially outwardly from a supporting rotor disk and surrounded by an annular turbine shroud. A low pressure turbine (LPT) follows the high pressure turbine and includes additional nozzles and rotor blades which may or may not include internal cooling circuits depending upon the engine design. An exhaust liner usually follows the low pressure turbine.

[0037] During the operation of a gas turbine engine like that described in the Lee patent, ambient air is pressurized by the fan mentioned above. A portion of the ambient air enters the compressor for additional pressurization, while the outer portion is discharged from a fan outlet for providing propulsion thrust in a turbofan engine application. The air pressurized in the compressor is mixed with fuel in the combustor for generating hot combustion gases. The combustion gases flow through the various turbine blade stages which extract energy therefrom for powering the compressor and fan during operation. Additional details regarding the architecture of such an engine can be found in the Lee patent, along with various other references.